Remote Sensing and Prediction of the Coastal Marine Boundary Layer

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LONG TERM GOALS

The long-term goal is to improve numerical (computer -aided) weather prediction in coastal regions, especially of weather events that impact naval operations.

OBJECTIVES

We seek to forecast weather events in the right place and the right time. The weather events we are most concerned with are convective storms, boundary layer clouds and drizzle. We emphasize the use of satellite and lightning data for model initialization. The measurement of our success would be improved forecasts by the Navy's mesoscale model COAMPS.

APPROACH

1. We will implement and assess known techniques into the Navy forecast model COAMPS, and develop new strategies that do not yet exist in any model. One aid in this approach is to compare COAMPS forecasts with those of the University of Oklahoma's Advanced Regional Prediction System (ARPS). This effort is abetted by our collocation with the NSF-funded Center for Analysis and Prediction of Storms and NOAA's National Severe Storms Lab. ARPS has existing interfaces that allow it to nest in the NCEP forecast models ETA and RUC. We have built the software interface that allows ARPS to nest in NOGAPS using the COAMPS initialization.

2. We aim to extend CAPS achievements in data assimilation. We are building and testing a new storm initialization strategy from a combination of existing CAPS technology (the ARPS Data Analysis System, or ADAS), and new theory and new data sources. The COAMPS model was originally designed to be initialized using the same data as the Navy's global model NOGAPS. The COAMPS forecast gives benefit over that of NOGAPS mainly in that COAMPS better resolves topography, coastlines and atmospheric events like thunderstorms, than does NOGAPS. There has been no extensive effort to incorporate extra retrieval or assimilation schemes specifically for COAMPS. On the other hand, there has been extensive development at OU to assimilate high space and time-resolution observations from both radar and surface networks into the initialization of ARPS, so as better to predict future thunderstorms and other mesoscale phenomena. The COAMPS and ARPS models are sufficiently similar that the COAMPS initialization can be successfully run through ADAS.

3. We use a large eddy simulation (LES) model developed by Dr. Kogan and his colleagues, with fairly detailed, accurate representations of physical process that occur in the atmospheric boundary layer (the lower ~1 km of atmosphere that is constantly exchanging heat, moisture and momentum with the surface of the Earth). The model has been verified against data from several field programs. The LES model is then used to find relationships between physical processes and states (such as drizzle production, aerosol cleansing, visibility, cloud cover, optical properties) and physical variables that are (or can be) forecasted in NWP models (humidity, aerosol concentration, etc.). The physical processes we are studying for the purpose of better representing them in NWP models (the "parameterization" process) mostly involve low, boundary layer clouds (fog, stratus).

4. We are looking at the effect of advection schemes on resolved storms and convective rainfall.

5. Our approach to better initialize atmospheric models involves using radar and satellite data to retrieve atmospheric quantities, and using the retrievals in constructing a physically consistent state of the current atmosphere. Specifically, we emphasize retrieving quantities that define structures with scales in the range of 1 to 100 km. These could be convergence lines, three-dimensional cloud positions, water vapor and cloud water distributions, boundary layer height, squall lines, seabreeze convergence clouds, fog or low-level clouds. Single-Doppler retrieval has a long history of development at the University of Oklahoma, a tradition we continue. The single-Doppler "problem" is to retrieve as much information about the wind vector and thermodynamic state as is possible from a time-series of radar measurements that at any instant in time is measuring only the component of wind aligned with the radar beam. Dr. Shapiro has developed a new 4DVAR single-Doppler retrieval technique. The retrieval is Lagrangian in nature and uses Newton's second law as a strong constraint. The University of Oklahoma's Dopplers on Wheels are suitable instruments for gathering data sets that allow for verification of single Doppler retrieval. Some of the data sets collected have scanning rates as high as 1.5 minutes/volume, and are appropriate for establishing the sensitivity of the retrievals to data of progressively degraded (thinned) temporal resolution. We aim to maintain and upgrade the DOWs and to deploy the DOWs in coastal field programs of benefit to the Navy.

6. Although far from a coastline, Oklahoma does have plenty of observational resources to verify the land-surface properties of boundary layer schemes in forecast models. The Oklahoma Mesonet provides an excellent opportunity to check out the fidelity of the surface physics in COAMPS.

7. Another boundary layer project is the development of a version of ARPS that moves gridpoints around in the vertical direction, into layers where they are immediately needed. ("Gridpoints" are the locations where values of atmospheric variables are stored - in almost all NWP models the locations do not change with time.) These layers where more gridpoints are needed are cloud layers and/or layers of strong vertical gradients. This is so-called "continuous dynamic grid adaption", or CDGA.

8. The LES model is also used as a guide to construct NWP parameterizations that will allow for stratocumulus clouds to break up naturally into honey-comb cloud patterns known as mesoscale cellular convection, or MCC. (The individual cells of MCC are typically 30 km across). The LES model output is treated as data. In constructing an NWP model as a subset of the LES model, non-essential processes are thrown out or simplified if the ability to simulate meoscale cloud structures is retained.

WORK COMPLETED

Five post-docs remained with us during the past year. The post-docs are Dr. Fanyou Kong, Dr. Zonghui Huo, Dr. Qingfu Liu, Dr. Pengfei Zhang, and Dr. Chinnaswamy Arulmani. An extensive array of networked workstations has been installed, with access to shared DEC Alpha workstations and the University of Oklahoma's (OU) CrayJ90.

1. Three case studies concern severe convective weather in Florida, the events of 23 April 1997, 2 February 1998 and 23 February 1998. COAMPS and ARPS comparisons have been conducted for all three. Dr. Kong has continued simulations of low cloud on the California coast with ARPS and COAMPS.

2. We have added the use of lightning data to the cloud initialization scheme of ADAS, and have also added a convective circulation initialization scheme.

3. This year, Dr. Kogan used the LES to explicitly resolve supersaturation and aerosol activation for the purposes of parameterizing the supersaturation and aerosol activation process in mesoscale models like ARPS and COAMPS. The drizzle parameterization consists of 6 prognostic variables: cloud water content, cloud drop concentration, total mean radius, drizzle water content, drizzle concentration and cloud condensation nuclei. The mesoscale version of this drizzle parameterization is similar to that which was developed by Dr. Kogan for LES models, except the mesoscale version predicts activation by supersaturation in a parameterization developed this year.

4. In a related study, we have demonstrated that COAMPS does not perform as well as ARPS in simulating resolved convection, and that COAMPS could be over-predicting rainfall for resolved convection.

5. Dr. Shapiro has further developed his new 4DVAR single-Doppler retrieval technique.
Dr. Wurman deployed the DOWs in CALJET/NORPEX during January and February 1998. Dual Doppler data sets were collected for use by CALJET/NORPEX and for use by Dr. Shapiro to verify his single-Doppler retrieval schemes.

6. In comparisons of COAMPS forecasts with Oklahoma Mesonet data on a July day when "nothing happened", we find the simple non-vegetated scheme in COAMPS and lack of sufficient soil moisture lead to expected errors.

7. We have built CDGA into a version of ARPS and have assessed the benefits of CDGA.

8. Dr. Fiedler has run the ARPS model as a high resolution (125 meters) *dry* LES in a 32 km square domain with periodic boundary conditions. Large-scale convection cells emerged over the course of two days until a single-cell dominated the domain. The LES simulations were then compared with the ARPS run as a mesoscale model with 1 km resolution, where most of the cumulus-scale transport was sub-grid. A significant analytical analysis of the cell broadening was discovered and submitted to the Journal of Fluid Mechanics.

RESULTS

1. In the three squall line comparisons with 24-km horizontal resolution and parameterized convection, COAMPS and ARPS perform similarly.

2. We have demonstrated the effectiveness of ADAS in aiding the initialization of the 23 April 1997 storm, and are well positioned to further develop storm initialization by using all three severe weather events in Florida as test cases.

3. The effect of the drizzle parameterization on COAMPS or ARPS forecasts is unknown.

4. The problems of COAMPS with resolved convection and the overprediction of rain have been shown to be probably due to the simple second-order advection scheme in COAMPS. We are currently

implementing a conservative, monotonic scheme into COAMPS, a scheme that has been used successfully in ARPS.

5. The DOWs functioned admirably during the entire CALJET/NORPEX field program and should contribute to the organizers' goals. Although the data suffers from attenuation in heavy rainfall, Dr. Shapiro has identified several data sets with which to do a single-Doppler retrieval, dual-Doppler verification.

6. We find ourselves in a position both to add better surface physics to COAMPS and to test it against a currently expanding and upgrading Mesonet that provides unique details about surface heat fluxes, ground heat flux and soil moisture across the state of Oklahoma.

7. CDGA does work and improves a forecast. But, as expected, the added complexity of the code and the lack of a robust method for optimally moving the grid points can remove all benefit of using such a code. Cautions have been issued about being optimistic about the benefits of CDGA in an operational model.

8. The fortuitous analytical solutions for cell-broadening in idealized dry conditions should greatly aid us in our study of mesoscale cellular convection (or lack thereof) in numerical weather prediction models.

IMPACT

We expect to be successful in offering to the meteorological community (and to the Navy in particular) improvements for numerical weather prediction of storms, boundary layer clouds and drizzle.

TRANSITIONS

Our colleagues at NRL are aware of the problems we have identified with the COAMPS advection schemes and surface physics. They can expect upgraded software from us in the near future. They also know about our efforts in data assimilation and can expect COAMPS compatible software near the end of the project. A Fortran to HTML converter developed by us is being used by the Meteo-France/CNRM/Mesoscale research group in France. The converter is freely available from our web site.

RELATED PROJECTS

We work closely with the personnel of OU's Center for Analysis and Prediction of Storms, the Oklahoma Climate Survey (Mesonet), and the Marine Meteorology Division of the Naval Research Laboratory.

PUBLICATIONS

We have been a participant in 8 refereed publications that have been accepted or conditionally accepted, and 21 conference preprints. Three notable papers are:

Fiedler, B.H., 1998: Thermal convection in a layer bounded by uniform heat flux: application of a strongly nonlinear analytical solution. Journal of Fluid Mechanics. (conditionally accepted)

Khairoutdinov, M. F. and Y. L. Kogan, 1998: A large eddy simulation model with explicit microphysics: validation against aircraft observations of a stratocumulus-topped boundary layer. J. Atmos. Sci., (accepted).

Shapiro, A., and J. Mewes, 1998: New formulations of dual-Doppler wind analysis. J. Atmos. Oceanic Technol. (accepted)